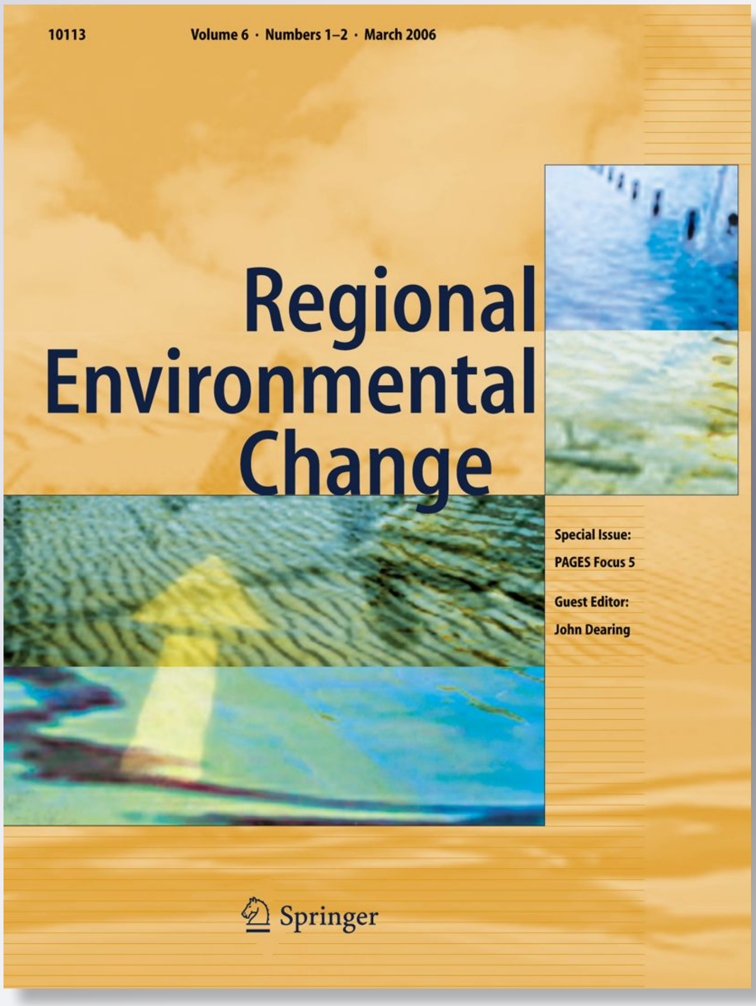
Late twentieth century land-cover change in the basin and range ecoregions of the United States

Christopher E. Soulard & Benjamin M. Sleeter

Regional Environmental Change

ISSN 1436-3798

Reg Environ Change
DOI 10.1007/s10113-012-0296-3



Reg Environ Change
DOI 10.1007/s10113-012-0296-3

ORIGINAL ARTICLE

Late twentieth century land-cover change in the basin and range ecoregions of the United States

Christopher E. Soulard · Benjamin M. Sleeter

Received: 16 September 2011 / Accepted: 23 February 2012

Abstract As part of the US Geological Survey's Land Cover Trends project, land-use/land-cover change estimates between 1973 and 2000 are presented for the basin and range ecoregions, including Northern, Central, Mojave, and Sonoran. Landsat data were employed to estimate and characterize land-cover change from 1973, 1980, 1986, 1992, and 2000 using a post-classification comparison. Overall, spatial change was 2.5% (17,830 km^2). Change increased steadily between 1973 and 1986 but decreased slightly between 1992 and 2000. The grassland/shrubland class, frequently used for livestock grazing, constituted the majority of the study area and had a net decrease from an estimated 83.8% (587,024 km^2) in 1973 to 82.6% (578,242 km^2) in 2000. The most common land-use/land-cover conversions across the basin and range ecoregions were indicative of the changes associated with natural, nonmechanical disturbances (i.e., fire), and grassland/shrubland loss to development, agriculture, and mining. This comprehensive look at contemporary land-use/land-cover change provides critical insight into how the deserts of the United States have changed and can be used to inform adaptive management practices of public lands.

Keywords Mojave · Sonoran · Great Basin · Fire · Development · Land use

C. E. Soulard (✉) · B. M. Sleeter
United States Department of the Interior, United States Geological Survey, Western Geographic Science Center, 345 Middlefield Road, MS-531, Menlo Park, CA 94025, USA
e-mail: csoulard@usgs.gov

Introduction

Land-use/land-cover (LULC) research is an important component in constructing a historical foundation from which long-term monitoring can extend (Lambin et al. 2001). Land surface monitoring has implications on biodiversity (Falcucci et al. 2007; Joseph et al. 2009), climate (Bradley 2010; Feddema et al. 2005), and carbon cycling change research (Houghton et al. 1999). Additionally, LULC studies employing remotely sensed imagery can be used to monitor the past (Cousins 2001) or to forecast LULC cover into the future (Sohl et al. 2010). Until recently, the amount of spatially and temporally consistent quantitative data describing the rates and types of LULC change across the basin and range ecoregions of the Western United States was somewhat limited. Previous studies focused on smaller areas, specific LULC characterizations, and (or) a narrow temporal range (Bradley and Mustard 2005; Brooks and Matchett 2006; Finn et al. 2004; McGwire et al. 2000; Smith et al. 1990; Ustin et al. 1986; Wallace and Webb 2008). In the past year, the US Geological Survey's Land Cover Trends research project completed a national effort aimed at mapping contemporary US land-use and land-cover change for the period 1973–2000 (Loveland et al. 2002). The project employs an ecoregion framework as its primary stratification unit (Omernik 1987). Ecoregions are defined as homogenous ecological regions with similar biotic, abiotic, terrestrial, and aquatic components, with humans included as part of the biota (McMahon et al. 2001). Ecoregions inherently have more cohesive stories of landscape change due to the high level of ecological similarities. Here, we have estimated regional LULC change for the four ecoregions within the basin and range province of the United States: Northern Basin and Range, Central Basin and Range, Mojave Basin and Range, and Sonoran Basin and Range ecoregions (Fig. 1).

The basin and range ecoregions of the Western United States make up a continuous area approximately 700,293 km^2 generally classified as desert. Basin and Range topography is the primary distinguishing characteristic of each ecoregion: desert valleys bordered by parallel mountain ranges generally oriented north to south. The elevation of mountains in each ecoregion varies significantly: numerous peaks within the Central Basin and Range ecoregion have summits higher than 3,000 meters, while the highest peak in the Sonoran Basin and Range ecoregion reaches 1,830 meters. The location of the basin and range province between major mountain ranges influences regional climate. The Sierra Nevada produces a rain shadow effect that blocks moisture coming from the Pacific Ocean, whereas the Rocky Mountains create a barrier effect that restricts moisture influx from the Gulf of Mexico (Rogers 1982). This lack of moisture creates the four biologically defined deserts in North America: the Great

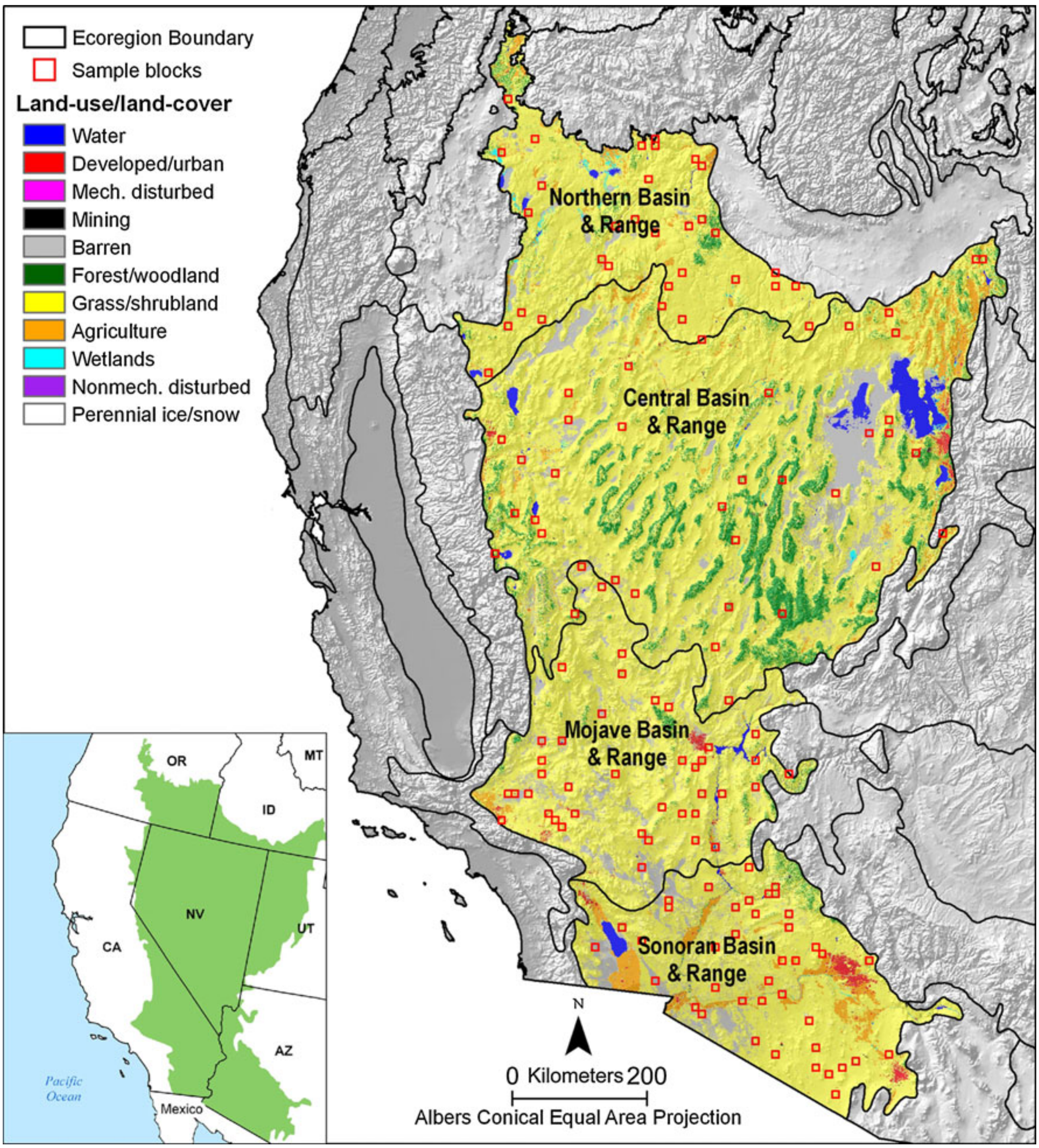


Fig. 1 Sample data consist of 148 sample blocks overlaying the Northern Basin and Range, Central Basin and Range, Mojave Basin and Range, and Sonoran Basin and Range ecoregions. Land-use/land-cover data are from the 1992 National Land Cover Dataset (Vogelmann et al. 2001) (*Mech* mechanically, *Nonmech* nonmechanically)

Basin, Mojave, Sonoran, and Chihuahuan (Grayson 1993). While these ecoregions collectively make up roughly one-tenth of the land area in the conterminous United States, roughly one-fifth of the grasslands/shrublands in the United States are located in the basin and range province. Notable variations exist between and within the basin and range ecoregions, such as the abundance of sagebrush in the cooler northern desert compared to the cactus-dominated land cover in the warmer southern desert. Climatic and geomorphologic similarities set the deserts apart from the rest of the Western United States and create a unique suite of LULC management issues.

Materials and methods

As part of the US Geological Survey's Land Cover Trends project, we employed a regionalized pure panel random sampling approach using 10-km by 10-km samples to characterize LULC change for five dates (1973, 1980, 1986, 1992, and 2000) and four discrete periods (1973–1980, 1980–1986, 1986–1992, and 1992–2000; Loveland et al. 2002; Stehman et al. 2003). Samples were stratified by EPA Level III ecoregions (Omernik 1987) of the conterminous United States. By employing a probability sampling approach using a geographic, ecoregion-based stratification, samples are not only distributed more evenly within ecoregions and between administrative units associated with the strata, but the precision of change estimates for each ecoregion is also improved by ensuring that an adequate number of samples are allocated to each ecoregion (Stehman 1999). Sampling does introduce the potential for exclusions of parts of the population, but the stratified random sampling used here is more effective than simple random sampling efforts because different LULC classes in each ecoregion strata are fairly represented in the samples.

Although the Land Cover Trends project is a national endeavor to map LULC change, we used only the basin and range ecoregions (Northern, Central, Mojave, and Sonoran) for this analysis. Between 32 and 40, sample blocks were randomly selected for each of the four ecoregions. Our sample data consist of 148 sample blocks selected from a population of 6,977 blocks distributed across all four ecoregions that collectively make up the majority of the desert lands in the conterminous United States (Fig. 1).

Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) satellite imagery were used to manually classify all features with a footprint greater than 60-m by 60-m into one of 11 general LULC classes based on the Anderson classification scheme (Anderson et al. 1976; Table 1). We included two

Table 1 Land-use/land-cover class descriptions

Class	Description
Water	Areas persistently covered with water, such as streams, canals, lakes, reservoirs, bays, or oceans
Developed/urban	Areas of intensive use with much of the land covered with structures (e.g., high-density residential, commercial, industrial, transportation, mining, and confined livestock operations) or less intensive uses where the land-cover matrix includes both vegetation and structures (e.g., low-density residential, recreational facilities, and cemeteries), including any land functionally attached to the urban or built-up activity
Mechanically disturbed[a]	Land in an altered and often unvegetated state that, due to disturbances by mechanical means, is in transition from one cover type to another. Mechanical disturbances include forest clear-cutting, earthmoving, scraping, chaining, reservoir drawdown, and other similar human-induced changes
Barren	Land comprised of natural occurrences of soils, sand, or rocks where less than 10% of the area is vegetated
Mining	Areas with extractive mining activities that have a significant surface expression. This includes (to the extent that these features can be detected) mining buildings, quarry pits, overburden, leach, evaporative, tailing, or other related components
Forests/woodlands	Tree-covered land where the tree-cover density is greater than 10%. Note that cleared forest lands (i.e., clearcuts) are mapped according to current cover (e.g., disturbed or transitional and shrubland/grassland)
Grassland/shrubland	Land predominately covered with grasses, forbs, or shrubs. The vegetated cover must comprise at least 10% of the area
Agriculture	Cropland or pastureland in either a vegetated or unvegetated state used for the production of food and fiber. Note that forest plantations are considered as forests or woodlands regardless of the use of the wood products
Wetland	Lands where water saturation is the determining factor in soil characteristics, vegetation types, and animal communities. Wetlands are comprised of water and vegetated cover
Nonmechanically disturbed[a]	Land in an altered and often unvegetated state that, due to disturbances by nonmechanical means, is in transition from one cover type to another. Nonmechanical disturbances are caused by wind, floods, fire, animals, and other similar phenomenon
Perennial ice/snow	Land where the accumulation of snow and ice does not completely melt during the summer period

[a] Category included to capture anthropogenic or natural disturbance events

categories of disturbance to capture anthropogenic (e.g., forest cutting) and natural (e.g., fire and insect damage) events (Loveland et al. 2002).

According to Sohl et al. (2007), manual imagery interpretation has a higher level of accuracy than automated techniques. Cross-sensor change detection typically involves rigorous image normalization processes, and preprocessing for registration, atmosphere, sun angle, elevation, etc., are critical for algorithm-based approaches (Serra et al. 2003; Wulder et al. 2008). However, manual interpretations allow for the use of different sensors (Sohl et al. 2004) where the interpreter can reconcile spatial and spectral differences between sensors without using normalization procedures. Despite these benefits, the Land Cover Trends Project outlined a sub-pixel accuracy objective in between-scene registration and attempted to minimize seasonal effects by using imagery from the same time of year where possible. A consistent projection was also used in all datasets.

A team of ten image interpreters were trained on manual classification mapping procedures to ensure mapping consistency. Interpreters manually identified areas of LULC change in the Landsat imagery with Erdas Imagine software. Historical aerial photographs, topographic maps, and other ancillary data sources were used to aid in image interpretation. In transitional lands, ancillary aids such as The Great Western Fire Map (Finn et al. 2004) and Monitoring Trends in Burn Severity (Eidenshink et al. 2007) database also helped confirm the presence and/or the cause of disturbances in each date. Spatial data and the literature not only improved the overall classification of the sample blocks, but also served as evidence to ascertain the drivers of land change (Napton et al. 2010). A traditional accuracy assessment was not conducted since ancillary data typically used to for sampling and testing classification errors were used by interpreters during the classification effort. Instead, sample blocks were checked for errors in an internal peer review process where Land Cover Trends researchers reviewed LULC maps for each sample block for each date. Upon completion of mapping, estimates of change and associated uncertainty were derived using post-classification comparison of LULC for each date.

Results

We present several collections of overall and regional-scale landscape change for the Northern, Central, Mojave, and Sonoran Basin and Range ecoregions. Estimates are presented as totals for the entire basin and range province, while highlighting notable regional variations. Overall, spatial change aggregated for the entire basin and range province for 1973–2000 is the broadest measurement of change. Similar estimates are provided by temporal interval at the ecoregion level. Estimates of landscape composition, common LULC conversions within each ecoregion, and error reporting follow.

Overall land-cover composition

The grassland/shrubland class, composed mostly of sagebrush or invasive grasses used for livestock grazing, constituted the majority of the study area (Table 2). Forest cover made up the second largest proportion of the study area. Three land-use classes, agriculture, developed, and mining, account for 3.7% of the overall land area in the basin and range province. Over the study period, disturbed lands (mechanically and nonmechanically disturbed) collectively ranged from less than 0.1% to just over 0.8% of the landscape. Water, wetland, snow/ice, and barren areas represent the remaining land cover. Overall, grassland/shrublands experienced the greatest net loss over the study period. LULC composition for the five dates (1973, 1980, 1986, 1992, and 2000) used in our analysis is presented in Table 2.

Overall and regional change summary

Overall, spatial change across the basin and range province, that is the area that changed at least one time between 1973 and 2000, was 3.0% (21,161 km^2) with 1.0% (6,991 km^2) of the region experiencing change in more than one time period. Multiple changes in individual pixels were generally associated with disturbance events and subsequent vegetation re-growth (e.g., fire), with some contributions from water and agricultural fluctuations. We found that change increased steadily in the first three time intervals from an average of 535 km^2 per year between 1973 and 1980 to 1,285 km^2 per year between 1986 and 1992. We estimated a small decline in the rate of change between 1992 and 2000, to an average change of 944 km^2 per year.

Overall, spatial change estimates (gross estimates) may show a minimal increase or decrease over time, yet do not provide any insight into regional LULC variability. An analysis at the ecoregion level suggests that change varied much more between ecoregions. Fire-dominated ecoregions (Northern Basin and Range was the most fire-prone, followed by the Central Basin and Range) exhibited the highest amount of land change, with less change in development-dominated ecoregions. For example, the Northern Basin and Range experienced the highest amount of change at 5.8% (6,392 km^2). The Central Basin and Range (1.5%; 4,959 km^2), Mojave Basin and Range (2.6%; 3,429 km^2), and Sonoran Basin and Range (2.6%; 3,040 km^2) experienced less amounts of change relative to

Table 2 Land-cover composition of the entire basin and range province (as a percentage of the study area and by corresponding area) shows that much of the change between 1973 and 2000 occurred in the grassland/shrubland class, followed by changes in the nonmechanically disturbed and developed classes

Year	Water	Developed	MD	Mining	Barren	Forest	Grass/shrub	Agriculture	Wetland	NMD	Ice
Land-cover composition (% area)											
1973	0.3%	0.5%	<0.1%	0.3%	3.2%	8.7%	83.8%	2.3%	0.8%	<0.1%	<0.1%
1980	0.4%	0.6%	0.1%	0.3%	3.2%	8.7%	83.6%	2.4%	0.7%	<0.1%	<0.1%
1986	0.5%	0.7%	<0.1%	0.3%	3.2%	8.7%	83.3%	2.4%	0.7%	0.2%	<0.1%
1992	0.3%	0.9%	0.1%	0.3%	3.2%	8.7%	83.0%	2.3%	0.7%	0.4%	<0.1%
2000	0.3%	0.9%	0.1%	0.4%	3.2%	8.7%	82.6%	2.4%	0.7%	0.7%	<0.1%
1973–2000 change	<0.1%	0.4%	0.1%	0.2%	<0.1%	−0.1%	−1.3%	0.1%	−0.1%	0.6%	<0.1%
Land-cover composition (km^2)											
1973	2,323	3,808	219	1,787	22,427	61,118	587,024	15,990	5,270	194	133
1980	3,054	4,270	478	1,915	22,406	61,090	585,265	16,770	4,905	<10	133
1986	3,202	4,754	291	2,085	22,364	61,028	583,673	16,806	4,711	1,248	133
1992	2,304	5,982	995	2,432	22,329	61,064	581,248	16,336	4,808	2,661	133
2000	2,399	6,636	987	2,856	22,335	60,682	578,242	16,473	4,858	4,693	133
1973–2000 change	76	2,828	768	1,069	−92	−436	−8,782	483	−413	4,500	0

MD mechanically disturbed, *NMD* nonmechanically disturbed

the Northern Basin and Range and compared to other ecoregions in the Western United States (Fig. 2).

Insights into temporal variability between ecoregions also illustrate a more complex story of change than overall spatial change estimates alone. For example, the Sonoran Basin and Range experienced its high amounts of change for the periods 1973–1980 and 1980–1986 before dropping off significantly for the final two time intervals.

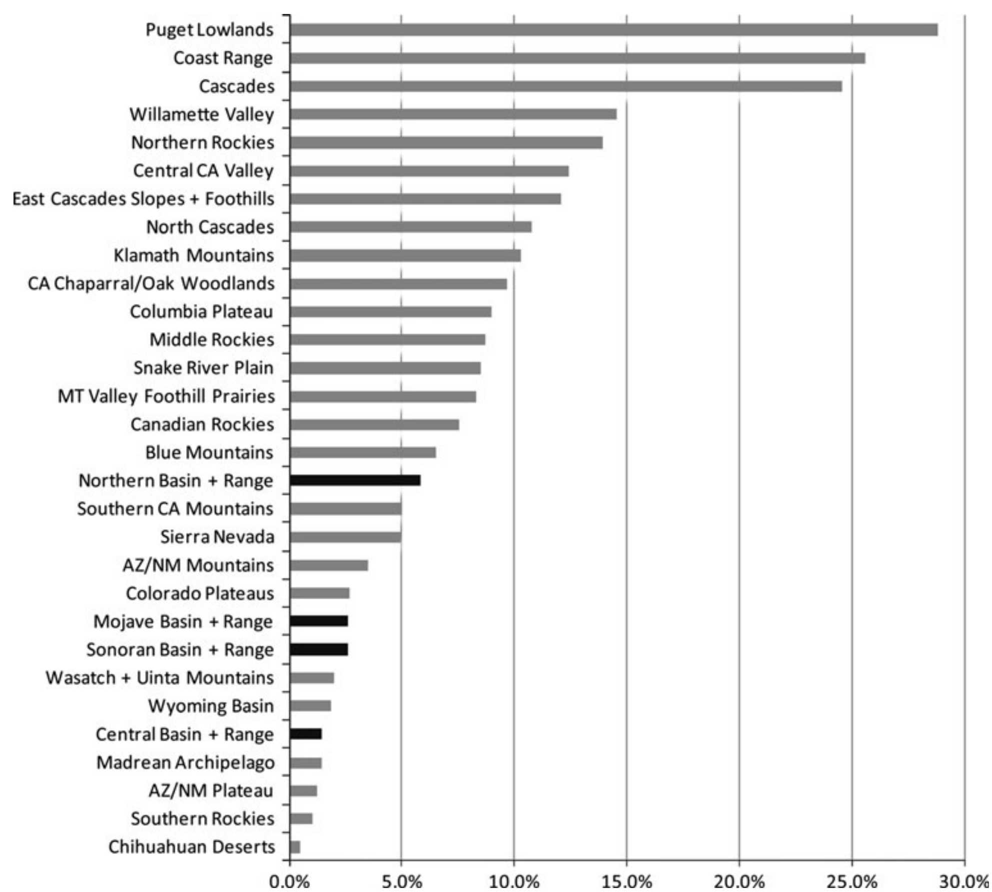


Fig. 2 Changed area as a percentage of ecoregion area for the 30 ecoregions in the Western United States. The basin and range ecoregions experienced low amounts of change compared to many of the western ecoregions

Conversely, the Mojave Basin and Range experienced its least amount of change during the first two intervals and the rate of urbanization was highest between 1986 and 1992. In the Central Basin and Range, change was highest between 1992 and 2000 owing largely to a sizeable increase in wildfire. The Northern Basin and Range also underwent a substantial increase in wildfire, but here wildfire frequency and magnitude reached its peak between 1986 and 1992, followed by considerable grassland and shrubland succession in previously burned areas between 1992 and 2000.

Land-cover composition change by ecoregion (1973–2000)

Developed land in the basin and range province increased by approximately 76% (2,828 km^2) between 1973 and 2000. 99% of new developed lands during the study period occurred in the Mojave Basin and Range, Sonoran Basin and Range, and Central Basin and Range ecoregions. Furthermore, 51% of the developed lands in the basin and range province in 1973 were located in the Mojave Basin and Range, which contains the Las Vegas, Palm Springs-Coachella Valley, and Lancaster-Palmdale metropolitan areas. By 2000, the Mojave Basin and Range accounted for about 59% of the developed land in the basin and range province, with developed areas having increased by 1,673 km^2. The Sonoran Basin and Range and Central Basin and Range gained about 481 and 646 km^2 of new development, respectively.

Large wildfires accounted for significant, albeit temporary, losses in grasslands/shrublands across the basin and range province. Nearly, all transitional fire disturbances occurred in the northern two ecoregions (Northern and Central Basin and Range ecoregions), with most of these changes between 1986 and 2000. Declines in grassland/shrubland were consistent over time with incremental losses across the basin and range province measured during each of the first three intervals. The increase in grasslands/shrublands in the final interval (1992–2000) was associated with grassland and shrubland succession in previously burned areas. The Northern Basin and Range ecoregion ranks the highest for grasslands/shrublands changes between 1973 and 2000, during which time it lost 3.6% from this class.

Nonmechanical disturbances are changes associated with wildfires, insect infestations, storms, and other "natural" events. Although nonmechanical disturbances driven by other causes may have occurred outside of the sampling blocks, ancillary datasets indicated that the nonmechanical disturbances mapped in the basin and range ecoregions' sample blocks were entirely associated with wildfire. Over the study period, the nonmechanical disturbance class experienced 8,720 km^2 in gross change across the basin and range ecoregions. Following a small decline in the first interval, the rate of nonmechanical disturbances across the basin and range ecoregions escalated in each of the following three intervals, from 207 km^2/year for 1980–1986 to 235 km^2/year for 1986–1992 to 254 km^2/year for 1992–2000. The Northern and Central Basin and Range ecoregions accounted for all of the mapped occurrences of wildfire.

Common land conversions

Providing estimates of change between two classes enhances thematic detail by quantifying the source, destination, and trajectory of specific LULC types and conversions. The most common LULC conversions across the entire basin and range province were changes associated with natural disturbances (i.e., fire), development, and to a lesser degree, agriculture, and mining (Table 3). Here, we identify and report change rates for specific LULC conversions in each of the 4 ecoregions.

Conversion of grassland/shrublands to nonmechanical disturbance totaled nearly 5,007 km^2 and was the largest land-cover conversion in the Northern Basin and Range ecoregion over the 27-year study period. When combined with nonmechanical disturbances in forested lands and areas that were previously burned, all fire-related disturbances totaled 6,539 km^2 account for roughly 60% of all changes in the ecoregion. 49% of all new, mapped fires occurred between 1986 and 1992. Areas such as the plains of the Owyhee Plateau of southern Oregon and Idaho were especially susceptible to fire over the study period, with large tracts of burned grasslands identified in the imagery. Following fire, areas that did not burn in consecutive dates experienced vegetation succession. Conversions from nonmechanical disturbance to grasslands/shrublands (1,379 km^2) and forest (1,148 km^2) totaled nearly 2,527 km^2, mostly occurring between 1992 and 2000 following the largest period of wildfire. Less common conversions consisted of the transitions to and from the water class (992 km^2), along with transitions from grassland/shrubland to land uses such as agriculture and mining.

Although less than half the magnitude of the fires in the Northern Basin and Range, fire was the largest conversion in the Central Basin and Range between 1973 and 2000. The cumulative effect of fire on grassland, shrubland, and forest resulted in 1,872 km^2 in vegetated land-cover transitions (32.5% of all changes). Significantly, smaller changes in agricultural lands include 527 km^2 converted from grassland/shrubland to agriculture and 503 km^2 from agriculture to grassland/shrubland. Changes in both natural and manmade water bodies were reflected as 640 km^2 converted from wetland to water, 255 km^2 converted from

Table 3 Common LULC conversions and corresponding standard errors across the entire basin and range province

Interval		Est. change (km^2)	Std. error (km^2)
1973–1980			
Grassland/shrubland	Agriculture	865	300
Grassland/shrubland	Water	637	414
Grassland/shrubland	Developed	367	165
Wetland	Water	357	265
Water	Mech. disturbed	256	231
1980–1986			
Grassland/shrubland	Nonmech. disturbed	1,248	717
Water	Grassland/shrubland	658	503
Wetland	Water	608	594
Water	Wetland	355	338
Grassland/shrubland	Developed	349	144
1986–1992			
Grassland/shrubland	Nonmech. disturbed	2,559	1,711
Nonmech. disturbed	Grassland/shrubland	1,137	650
Grassland/shrubland	Developed	1,086	596
Grassland/shrubland	Mech. disturbed	486	291
Agriculture	Grassland/shrubland	482	222
1992–2000			
Grassland/shrubland	Nonmech. disturbed	2,143	1,361
Nonmech. disturbed	Nonmech. disturbed	1,389	1,368
Forest	Nonmech. disturbed	1,159	1,007
Nonmech. disturbed	Forest	1,147	1,130
Grassland/shrubland	Developed	529	196
Overall: 1973–2000[a]			
Grassland/shrubland	Nonmech. disturbed	5,950	2,301
Grassland/shrubland	Developed	2,332	664
Grassland/shrubland	Agriculture	1,653	384
Nonmech. disturbed	Nonmech. disturbed	1,491	1,372
Nonmech. disturbed	Grassland/shrubland	1,461	682
Forest	Nonmech. disturbed	1,159	1,007
Nonmech. disturbed	Forest	1,147	235
Water	Grassland/shrubland	1,091	546
Grassland/shrubland	Mining	1,029	1,130
Wetland	Water	1,029	651
Agriculture	Grassland/shrubland	962	267
Grassland/shrubland	Water	947	446

The standard error represents the uncertainty (±) of each change estimate. All conversions less than 900 km^2 for 1973–2000 were excluded here

mech Mechanically, *nonmech* nonmechanically

[a] Some overall conversions may reflect locations that experienced a specific LULC change in more than one interval, such as locations that burned more than once

water to grasslands/shrublands, 222 km^2 converted from grasslands/shrublands to water, and 178 km^2 converted from water to wetland. Unidirectional changes included transitions from the grassland/shrubland class to developed (538 km^2) and mining lands (526 km^2; Soulard 2006).

Changes associated with increased development were much larger in the Mojave Basin and Range, totaling 1,673 km^2 (44.4% of all changes) between 1973 and 2000. New areas of developed land were most often associated with the conversion of grasslands/shrublands, disturbed transitional land, and agriculture for urban uses. Grasslands/shrublands (1,402 km^2) were the primary sources for new developed areas accounting for 84% of all conversion to developed. 53% (751 km^2) of grassland/shrubland conversions to developed land occurred between 1986 and 1992 (Sleeter and Raumann 2006). Other common LULC conversions between 1973 and 2000 include grasslands/shrublands converting to mechanically disturbed lands, and mining and forest converting to mechanically disturbed lands.

Over the study period, new developed lands (481 km^2) were most often associated with the conversion of grasslands/shrublands and agriculture for urban uses. Changes in both natural and manmade water bodies and agricultural relocation also played a large role in Sonoran Basin and Range LULC change. Conversions between grasslands/shrublands and water account for roughly 32% (1,515 km^2) of all LULC change in the Sonoran Basin and Range. Water saw an initial increase between 1973 and 1980 with high amounts of change from grasslands/shrubs and wetlands (881 km^2), then saw a sharp drop between 1980 and 1986 as it reverted back to vegetation (1,001 km^2).

Uncertainty of change

Table 4 shows estimates and corresponding errors for overall annual change per interval. Uncertainty in change estimates range from roughly 150–250 km^2 per year for each of the reported change rates.

Although these standard errors serve to inform the confidence in our estimates, we found all reported overall estimates to be statistically significant. However, ecoregion level and conversion-specific reporting were not always statistically significant at an 85% confidence interval. The confidence in any change estimate is dependent on the assumption that the LULC change has a near-normal distribution, so rare changes create uncertainty in our estimates and limit our ability to make firm conclusions regarding certain estimated changes.

As a whole, the basin and range ecoregions are known to be areas with low change, which makes most changes rare when they do occur. To provide some context, let us look at two cases of changes as examples. Fire, although not seen as a rare event in the Western United States, is episodic in nature. Between 1973 and 2000, we found that 8 of our 148 samples in the entire basin and range province had mapped instances of fire, resulting in an estimated loss of 8,720 km^2 in vegetated land cover. Although we can collectively discuss the presence of fire within the 4 basin and range ecoregions, the infrequency of these changes contributed to such large errors in per-interval fire estimates that these estimates are not statistically significant. Our ability to report other episodic changes, such as water fluctuations, was also accomplished with varying degrees of uncertainty. Higher uncertainty arises where sampled changes are rare, clustered within small areas or do not follow a near-normal change distribution. Instances of surface water are uncommon in the region, with only 2,399 km^2 estimated in 2000. Changes in water areas did not appear to be so uncommon based on field collection and mapping efforts; yet, the distribution of change across the samples resulted in errors making it difficult to determine the significance of ecoregion-specific water fluctuations. More specifically, we can confidently discuss the initial increase in surface water and eventual decline as an overall land-cover trend, but cannot affirm the significance of the fluctuations in natural and manmade water bodies in the Sonoran Basin and Range, since the majority of changes were clustered in only three blocks and errors were large.

Table 4 Changes are shown as a percentage of the study area (700,293 km^2) that changed during each interval

Interval	Change estimate (%)	Standard error (%)	Relative error (%)	Average annual (%)
All basin and range ecoregions				
1973–1980	0.53%	0.10%	19%	0.08%
1980–1986	0.72%	0.17%	23%	0.12%
1986–1992	1.10%	0.29%	26%	0.18%
1992–2000	1.08%	0.30%	28%	0.13%

The standard error to change ratio is reported as the relative error. Rates were normalized by interval length to create average annual rates

Discussion

The spatially and temporally consistent data presented in this article not only describe the rates and types of LULC change across the basin and range ecoregions of the Western United States, but also provide the first comprehensive look at contemporary change in these arid lands. Discussing these ecoregions in the context of a national thematic study like Land Cover Trends proves useful as an illustration of relative extent of land surface change (Napton et al. 2010). The magnitude of LULC change varies significantly between ecoregions, but each experienced relatively low amounts of land change relative to the broader Western United States for the period 1973–2000 (Fig. 2; Sleeter et al. 2010). However, contemporary land change becomes significant at the national level when considering the substantial size of the basin and range ecoregions and the combination of changes that occurred between 1973 and 2000. Collectively, fire, development, agriculture, and mining contributed to the substantial loss of grasslands and shrublands across the basin and range ecoregions, with 35% of all grassland/shrubland fires and 7% of all new development in grassland/shrublands in the United States over the study period occurring in these four regions. Although the grassland/shrubland class only decreased by 1.2% over the 27-year study period, the loss of grassland/shrubland to other land types accounted for 18% of all grassland/shrubland losses in the United States between 1973 and 2000.

Substantial differences were observed between ecoregions for large grassland/shrubland conversions. Between

1973 and 2000, nonmechanical fire disturbances played a notable role in the story of grassland/shrubland change in the northern basin and range ecoregions (Northern and Central Basin and Range) while development-driven grassland/shrubland conversions dominated the southern ecoregions (Mojave and Sonoran Basin and Range). Much of the fires in the Northern and Central Basin and Range ecoregions have likely been driven by the replacement of sagebrush communities (*Artemisia*) by introduced annual grasses such as cheatgrass (*Bromus tectorum*). Cheatgrass and other annual grasses were primarily spread through livestock grazing in the Great Basin, but flourished because they were well adapted to low precipitation and filled an unoccupied resource niche (Knapp 1996). These grasses also favor frequent fires over the historical vegetation regime (Keeley 2006) and often replace native vegetation following fire events.

We mapped medium-to-large tracts of grasslands/shrublands converted to developed uses for each of the ecoregions with the exception of the Northern Basin and Range, often in the form of new development along highways or suburban housing surrounding established urban centers. Most of these developed class conversions occurred in the Mojave and Sonoran Basin and Range, where a number of factors led to urban expansion. Migration from Los Angeles, local military installations, and recreation opportunities in cities like Las Vegas are all possible drivers for expanded development in Las Vegas, Palm Springs-Coachella Valley, and Lancaster-Palmdale (Hunter et al. 2003). Additionally, favorable weather and cost of living in Phoenix-Tucson have driven retiree relocation to the Sonoran Desert. According to the US Census Bureau, the counties that make up the Sonoran Desert have increased by over 300% between 1960 and 2000 (US Census Bureau 2000). According to our mapping efforts, the growth in the developed footprint across the Sonoran Basin and Range ecoregion between 1973 and 2000 marked a 273% increase in developed lands in this region.

LULC change has a widespread effect on human life and wildlife in the basin and range. The economic benefits of land-use development are obvious: the infrastructure created through new land uses serves to benefit humans by creating jobs, energy, and food and fiber. Cities like Las Vegas, NV and Phoenix, AZ have grown substantially, creating sizable economies in the process. Wildlife may also benefit from human land uses in rare cases. Although desert riparian areas have been cited as critical management areas important for wildlife diversity and susceptible to land-use change (Chaney et al. 1993; Knopf et al. 1988), vegetated suburban habitats have proven to be suitable habitats for select riparian birds in the Southwest (Rosenberg et al. 1987).

More often, human influences tend to have a significant impact in these ecoregions since deserts are especially sensitive to landscape changes: LULC change can result in potentially long-lasting impacts on regional flora and fauna when LULC changes do occur (Brussard et al. 1998; Chambers and Miller 2004; Pellant et al. 2004). Shifts in land use across these regions contract or degrade wildlife habitats, leading to many species being classified as species of conservation concern (Oregon Department of Fish and Wildlife 2006; Rowland et al. 2006). Additional land-cover disturbances such as fire contribute to the significant loss of wildlife and reduction in biodiversity through the introduction of invasive species (Brooks and Esque 2002; Brooks and Pyke 2001; Haubensak et al. 2009; Larrucea and Brussard 2008). Grazing on grasslands/shrublands has changed the contemporary fire regime, ultimately contributing to the loss of native plant communities in the region and replacement by non-native, fire-prone grasses (Brooks and Matchett 2006; Haubensak et al. 2009; Miller et al. 2001). Overall, the decline of grasslands/shrublands along with the increase in fire and development has likely degraded biodiversity-rich ecosystems vital to the fitness of many vertebrate, invertebrate, and floral species. Based on 1991 dollar values presented by Knapp (1996) for BLM districts in the Northern Great Basin, the total cost of fires in desert landscapes is approximately \$50/acre when many of the resources impacted by fire are accounted for. Economic impacts include the loss of agricultural forage and tourism, while biophysical consequences include the degradation of soils and wildlife habitat. The impact on humans and animal life will likely be exacerbated in the future if current land use and disturbance change trajectories continue. The ability to create a link between LULC transitions and LULC change impacts, and to use change trends to prepare for future issues, has implications on land management, particularly in a region where preserving biodiversity is a high priority (Bureau of Land Management 2001; Stein et al. 2000).

This article presents the first comprehensive land change analyses for the basin and range ecoregions and helps develop a historical foundation describing LULC change in the region to guide future research. The regional land change data presented here can also be tied to local case studies on change impacts to improve land management in different biophysical, socioeconomic, and land management settings. In the case of land management, roughly 74% of the study area is managed as Federal land; however, LULC composition, LULC changes, and management objectives are unique for each managing agency (Berry et al. 2006). LULC trends describing how the loss of grassland/shrubland cover, the increasing presence of fire, and expanding development are distributed across ecoregions can be coupled with plant and animal distribution information and species-specific ecological requirements to identify habitat management areas across management units. Specifically, overarching LULC data in this paper describing the higher rate of fire in the Northern Basin and Range compared to the Mojave or Sonoran can be used in conjunction with location-specific information and consequences identified in the literature to help inform and prioritize fire management practices across the desert. Furthermore, the drying trend and increased likelihood for extreme weather events forecasted for the desert Southwest (Archer and Predick 2008; Brown et al. 2004) poses an increased fire risk within basin and range ecoregions where fuel accumulation in grass and shrub communities in anomalously wet years followed by low precipitation creates a high fire risk (Kipfmueller and Swetnam 2000). These prospective conditions present an added challenge for land managers to prepare for more fire hazards and mitigate the impact on humans and wildlife. As land managers attempt to anticipate how LULC change will be distributed across the basin and range ecoregions into the future, contemporary land change estimates will also provide invaluable insights into future scenarios of landscape change (Zhu et al. 2010). The US Geological Survey's Land Cover Trends project intends to explore future LULC compositions based on alternative future scenarios and investigates the role of human and biophysical influences as LULC change drivers in the basin and range ecoregions.

Acknowledgments This study was supported by the US Geological Survey (USGS) Geographic Analysis and Monitoring (GAM) program and Office of Global Change, the US Environmental Protection Agency, and NASA's Land-cover and Land-use Change Program. We thank the entire USGS Land Cover Trends Team and Laura Norman, Janis Taylor, and Tamara Wilson for providing constructive reviews of the manuscript.

References

Anderson JP, Hardy EE, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data. US Geological Survey professional paper 964, p 28

Archer SR, Predick KI (2008) Climate change and ecosystems of the southwestern United States. Rangelands 30:23–28

Berry KH, Murphy RW, Mack J, Quillman W (2006) Introduction to the special issue on the changing Mojave Desert. J Arid Environ 67(Supplement 1):5–10

Bradley BA (2010) Assessing ecosystem threats from global and regional change: hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. Ecography 33:198–208

Bradley BA, Mustard JF (2005) Identifying land cover variability distinct from land cover change: cheatgrass in the Great Basin. Remote Sens Environ 94:204–213

Brooks ML, Esque TC (2002) Alien annual plants and wildfire in desert tortoise habitat: status, ecological effects, and management. Chelon Conserv Biol 4:330–340

Brooks ML, Matchett JR (2006) Spatial and temporal patterns of wildfires in the Mojave Desert, 1980–2004. J Arid Environ 67:148–164

Brooks ML, Pyke D (2001) Invasive plants and fire in the deserts of North America. In: Galley KE, Wilson TP (eds) Proceedings of the invasive species workshop: the role of fire in the control and spread of invasive species. Fire conference 2000: the first national congress on fire ecology, prevention and management. Misc. Publ. No. 11, Tall Timbers Research Station, Tallahassee, FL, pp 1–14

Brown TJ, Hall BL, Westerling AL (2004) The impact of twenty first century climate change on wildland fire danger in the western United States: an applications perspective. Clim Change 62:365–388

Brussard PF, Charlet DA, Dobkin DS, Ball LC, Bishop KA, Britten HB, Fleishman E, Fleury SC, Jenni T, Kennedy TB, Mullen CO, Peacock MM, Prusso D, Reed M, Riley L, Rust RW, Simpkin JL, Vinyard G, Yandell UG, Marlow R, Charlet DA (1998) Great Basin-Mojave desert region. In: Mac MJ, Opler PA, Puckett Haeker CE, Doran PD (eds) Status and trends of the nation's biological resources. US Geological Survey, v. 2, Reno, Nevada

Bureau of Land Management (2001) The Great Basin restoration initiative—a hand in nature: progress to date. http://www.blm.gov/pgdata/etc./medialib/blm/id/fire/gbri/documents.Par.98895.File.dat/gbri_progress_9-01.pdf. Accessed 11 March 2011

Census Bureau US (2000) American FactFinder. US Census Bureau, Washington, DC

Chambers JC, Miller JR (2004) Great Basin riparian areas; ecology, management, and restoration: society for ecological restoration international. Island Press, Washington, DC, p 303

Chaney E, Elmore W, Platts WS (1993) Livestock grazing on western riparian areas. US Government Printing Office, Washington, DC, p 45

Cousins SA (2001) Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. Landscape Ecol 16:41–54

Eidenshink J, Schwind B, Brewer K, Zhu ZL, Quayle B, Howard S (2007) A project for monitoring trends in burn severity. Fire Ecol 3:3–21

Falcucci A, Maiorano L, Biotani L (2007) Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. Landscape Ecol 22:617–631

Feddema JJ, Oleson KW, Bonan GB, Mearns LO, Buja LE, Meehl GA, Washington WM (2005) The importance of land-cover change in simulating future climates. Science 310:1674–1678

Finn SP, Hanser SE, Meinke CW, Smith A (2004) The Great Western fire map (<=2003). http://sagemap.wr.usgs.gov/ftp/regional/USGS/Fires_WNA_sgca.zip. Accessed 15 March 2011

Grayson DK (1993) The desert's past: a natural prehistory of the Great Basin. Smithsonian Institution Press, Washington, DC, p 356

Haubensak K, D'Antonio C, Wixon D (2009) Effects of fire and environmental variables on plant structure and composition in grazed salt desert shrublands of the Great Basin (USA). J Arid Environ 73:643–650

Houghton RA, Hackler JL, Lawrence KT (1999) The US carbon budget: contributions from land-use change. Science 285:574–578

Hunter LM, Gonzalez MJ, Stevenson M, Karish KS, Toth R, Edwards TC, Lilieholm RJ, Cablk M (2003) Population and land use change in the California Mojave; natural habitat implications of alternative futures. Popul Res Policy Rev 22:373–379

Joseph S, Blackburn GA, Gharai B, Sudhakar S, Thomas AP, Murthy MSR (2009) Monitoring conservation effectiveness in a global biodiversity hotspot: the contribution of land cover change assessment. Environ Monit Assess 158:169–179

Keeley JE (2006) Fire management impacts on invasive plants species in the Western United States. Conserv Biol 20:375–384

Kipfmueller KF, Swetnam TW (2000) Fire-climate interactions in the Selway-Bitterroot wilderness area. USDA Forest Service Proceedings RMRS-P-15-Vol-5

Knapp PA (1996) Cheatgrass (*Bromus tecforum* L) dominance in the Great Basin Desert: history, persistence, and influences to human activities. Global Environ Change 6(1):37–52

Knopf FL, Johnson RR, Rich T, Samson FB, Szaro RC (1988) Conservation of riparian ecosystems in the United States. Wilson Bull 100:272–284

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environ Change 11:261–269

Larrucea ES, Brussard PF (2008) Shift in location of pygmy rabbit (*Brachylagus idahoensis*) habitat in response to changing environments. J Arid Environ 72:1636–1643

Loveland TR, Sohl TL, Stehman SV, Gallant AL, Say-ler KL, Napton DE (2002) A strategy for estimating the rates of recent United States land-cover changes. Photogram Eng Remote Sens 68(10):1091–1099

McGwire K, Minor T, Fenstermaker L (2000) Hyperspectral mixture modeling for quantifying sparse vegetation cover in arid environments. Remote Sens Environ 72:360–374

McMahon G, Gregonis SM, Waltman SK, Omernik JM, Thorson TD, Freeouf JA, Rorick AH, Keys JE (2001) Developing a spatial framework of common ecological regions for the conterminous United States. Environ Manage 28(3):293–316

Miller R, Baisan C, Rose J, Pacioretty D (2001) Pre- and post-settlement fire regime in mountain big sagebrush steppe and aspen: the northwestern Great Basin. National Interagency Fire Center, Corvallis

Napton DE, Auch RF, Headley R, Taylor J (2010) Land changes and their driving forces in the Southeastern United States. Reg Environ Change 10(1):37–53

Omernik JM (1987) Ecoregions of the conterminous United States. Ann Assoc Am Geogr 77:118–125

Oregon Department of Fish and Wildlife (2006) Oregon conservation strategy. Oregon Department of Fish and Wildlife, Salem, p 374

Pellant M, Abbey B, Karl S (2004) Restoring the Great Basin Desert, USA.; integrating science, management, and people. Environ Model Assess 99:169–179

Rogers GF (1982) Then and now: a photographic history of vegetation change in the central Great Basin desert: Salt Lake City. University of Utah Press, Utah

Rosenberg KV, Terrill SB, Rosenberg GH (1987) Value of suburban habitats to desert riparian birds. Wilson Bull 99:642–654

Rowland MM, Wisdom MJ, Suring LH, Meinke CW (2006) Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biol Conserv 129:323–335

Serra P, Pons X, Sauri D (2003) Post-classification change detection with data from different sensors: Some accuracy considerations. Int J Remote Sens 24(16):3311–3340

Sleeter BM, Raumann CG (2006) Land-cover trends in the Mojave Basin and range ecoregion. US Geological Survey Scientific Investigations Report 2006-5098, 15 p

Sleeter BM, Wilson TS, Soulard CE, Liu J (2010) Estimation of late twentieth century land-cover change in California. Environ Manage Assess 173:251–266

Smith MO, Ustin SL, Adams JB, Gillespie AR (1990) Vegetation in deserts: a regional measure of abundance from multispectral images. Remote Sens Environ 31:1–26

Sohl TL, Gallant AL, Loveland TR (2004) The characteristics and interpretability of land surface change and implication on project design. Photogram Eng Remote Sens 70(4):439–448

Sohl TL, Sayler KL, Drummond M, Loveland TR (2007) The FORE-SCE Model: a practical approach for projecting land use change through 2020 using a scenario-based modeling technique. J Land Use Sci 2(2):103–126

Sohl TL, Loveland TR, Sleeter BM, Sayler KL, Barnes CA (2010) Addressing foundational elements of regional land-use change forecasting. Landscape Ecol 25:233–247

Soulard CE (2006) Land-cover trends of the central basin and range ecoregion. US Geological Survey Scientific Investigations Report 2006-5288, p 20

Stehman SV (1999) Basic probability sampling designs for thematic map accuracy assessment. Int J Remote Sens 20(12):2423–2441

Stehman SV, Sohl TL, Loveland TR (2003) Statistical sampling to characterize recent United States land-cover change. Remote Sens Environ 86(4):517–529

Stein BA, Kutner LS, Adams JS (2000) Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York, p 399

Ustin SL, Adams JB, Elvidge CD, Rejmanek M, Rock BN, Smith MO, Thomas RW, Woodward RA (1986) Thematic mapper studies of semiarid shrub communities. Bioscience 36(7):446–452

Vogelmann JE, Howard SM, Yang L, Larson CR, Wylie BK, van Driel N (2001) Completion of the 1990s national land cover data set for the conterminous United States from landsat thematic mapper data and ancillary data sources. Photogram Eng Remote Sens 67:650–662

Wallace CA, Webb RH (2008) Estimation of perennial vegetation cover distribution in the mojave desert using MODIS-EVI data. GI Sci Remote Sens 45:167–187

Wulder MA, Butson CR, White JC (2008) Cross-sensor change detection over a forested landscape: options to enable continuity of medium spatial resolution measures. Remote Sens Environ 112:796–809

Zhu Z, Bergamaschi B, Bernknopf R, Clow D, Dye D, Faulkner S, Forney W, Gleason R, Hawbaker T, Liu J, Liu S, Prisley S, Reed B, Reeves M, Rollins M, Sleeter B, Sohl T, Stackpoole S, Stehman S, Striegl R, Wein A, Zhu Z (eds) (2010) A method for assessing carbon stocks, carbon sequestration, and greenhouse-gas fluxes in ecosystems of the United States under present conditions and future scenarios. US Geological Survey Scientific Investigations Report 2010–5233, 190 p. http://pubs.usgs.gov/sir/2010/5233/. Accessed 8 March 2011